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THERMOELECTRIC TEMPERATURE SCALES

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Research Paper No. 99

Reprint from Bureau of Standards Journal of Research
Vol. 3, September, 1929

For sale by the Superintendent of Documents, Washington, D. C. - - - Price 5 cents

RP 99

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By Wm. F. Roeser

ABSTRACT

The International Temperature Scale, adopted in 1927 by the Seventh General Conference of Weights and Measures, representing 31 nations, is the fourth thermoelectric temperature scale used by the Bureau of Standards since 1912. In putting this scale into use it was necessary for the Bureau of Standards to replace all of the fixed points used previous to 1926 by new fixed points specified in the International Temperature Scale. It is the purpose of this work to determine how much change this has caused in the temperature scale and to make available comparisons between the various scales used by the Bureau of Standards at different times since 1912.

The difference between four thermoelectric temperature scales based upon (1) Sb, Ag, and Au; (2) Zn, Sb, Ag, and Au; (3) Zn, Al, and Cu; and (4) Zn, Sb, and Cu as calibration points have been determined. The maximum difference between (1) and (2) was found to be 0.1° C., between (1) and (3) 0.2° C., and between (1) and (4) 0.3° C. in the temperature range 660° to 1,063° C.

The freezing point of the copper-silver eutectic alloy, 71.9 per cent silver and 28.1 per cent copper, on the International Temperature Scale was found to be 779.4° C. ±0.1° C.

The difference between the freezing points of gold and copper was found to be 20.0° C. ±0.1° C.

Methods used at the Bureau of Standards in realizing the International Temperature Scale in the range 660° to 1,063° C. are described in detail.

CONTENTS

I. INTRODUCTION

The International Temperature Scale [1] adopted in 1927 defines temperatures in the range 660° to 1,063° C. as follows:

* * * The temperature t is deduced from the electromotive force e of a standard platinum v. platinum-rhodium thermocouple, one junction of which is kept at constant temperature of 0° C., while the other is at the temperature t defined by the formula

$$e=a+bt+ct^2$$

The constants a, b, and c are to be determined by calibration at the freezing point of antimony and at the silver and gold points.

[1] Proc. Seventh General Conference of Weights and Measures, 1927, p. 56. Text in Annex IV, p. 94. G. K. Burgess, B. S. Jour. Research, 1, p. 635; October, 1928.

Previous to the adoption of the International Temperature Scale by the national laboratories several other thermoelectric temperature scales had been extensively used, and much data had been published in terms of these various scales. So far no data are available which give accurately the differences between all of these various scales. Henning and Otto [2] have published the difference between the average calibrations of two thermocouples, which give a comparison between the thermoelectric temperature scale previously used by the Physikalisch-Technische Reichsanstalt and the International Temperature Scale. Since it is important to be able to compare results expressed in terms of any one of the scales with those expressed in terms of another scale, it is highly desirable that the differences between some of the other scales be accurately determined.

The International Temperature Scale is intended to reproduce as closely as can be done with present knowledge the Centigrade Thermodynamic Temperature Scale, on which the temperature of melting ice and of condensing water vapor, both under the pressure of one standard atmosphere, are numbered 0° and 100°, respectively. This scale would be exactly realized with an ideal gas in a perfect gas thermometer and may be closely realized with the more permanent of the actual gases. From the departure of certain properties of these gases from those of an ideal gas it is possible to deduce the amount of the departure of the temperature scales, defined by their use, from the thermodynamic scale.

The gas thermometer is not a convenient instrument for ordinary use, and except under the most favorable conditions has not yielded results of high accuracy. The results of the best gas thermometer determinations have been made permanently available in the form of values for the temperatures of certain thermometric fixed points, such as freezing or boiling points of pure substances. The values accepted for such points depend not upon individual observations with one instrument nor upon a series of such observations, but are the weighted means of all published data, and are therefore more reliable than any single determination or series of determinations. Temperatures up to the melting point of palladium have thus been determined with the gas thermometer. These thermometric fixed points can be used in defining practical temperature scales with the aid of convenient interpolation instruments, such as thermocouples or resistance thermometers. The precision attainable with these thermometers calibrated at suitable fixed points is far greater than has been attained with the gas thermometer, except at very low temperatures

[2] Henning and Otto, Zeit. f. Phys. 49, p. 742; 1928.

II. PRACTICAL TEMPERATURE SCALES

The definition of any practical temperature scale must specify (1) values for the reproducible temperatures at which instruments are to be calibrated, (2) the type of instruments to be used in the realization of the temperature scale, and (3) the form of the equation to be used for interpolating between or extrapolating beyond the calibration points.

Prior to the adoption of the International Temperature Scale the platinum to platinum-10 per cent rhodium thermocouple was almost universally used for defining temperature scales in the range 450° to 1,100° C., and the equations used were either the quadratic $E=a+bt+ct^2$ or the cubic $E=a+bt+ct^2+dt^3$, depending upon the number of calibration points.

Thermoelectric temperature scales which have been extensively used for defining temperatures in the range 450° to 1,100° C. are described below. In all cases the platinum to platinum-10 per cent rhodium thermocouple has been the instrument used in the realization of these scales.

The scale based upon the work of Holborn and Day [3] was defined by the thermocouple calibrated at the freezing point of zinc (419.0°C.) antimony (630.6° C.) and copper (1,084.1° C.) with the quadratic equation for interpolating. This scale with the above values was almost universally used from 1900 to 1909. The work of Waidner and Burgess [4] in 1909 and of Day and Sosman [5] in 1910 and 1912 necessitated a readjustment of the above values, and in 1912 the Bureau of Standards redefined its scale, retaining the quadratic equation but assigning values determined with the resistance thermometer to the freezing points of the zinc and antimony in use, while the freezing point of copper was taken as 1,083.0° C. Here for convenience this 1912 scale of the Bureau of Standards, which was used from, 1912 to 1916, will be designated as the Zn, Sb, and Cu temperature scale.

The temperature scale proposed by Sosman [6] and revised by Adams,[7] both of the Geophysical Laboratory, was realized by using a standard reference table, which gives the average temperature-emf relation for several of the thermocouples used by Day and Sosman. A deviation curve is determined for any other thermocouple by calibration at several, preferably three or more of the fixed points, the values for which were determined by Day and Sosman,

[3] Holborn and Day, Am. J. Sci., **10**, p. 17; 1900.

[4] Waidner and Burgess, B. S. Bull., **6**, No. 2, p. 149; 1909.

[5] Day and Sosman, Car. Inst. of Wash. Pub. No. 157; 1911. Am. J. Sci. **33**, p. 517; 1912.

[6] R. B. Sosman, Am. J. Sci. (4), **30**, p. 7; 1910.

[7] L. H. Adams, J. Am. Chem. Soc., **36**, p. 65; 1914.

and then plotting the difference between the observed emf and the emf from the reference table against the observed emf of the thermocouple. This scale, although very convenient, is not completely defined in that it does not specify the particular calibration points to be used. Because of this lack of definition it was not feasible to make comparison between this scale and others described here.

In 1916 the Physikalisch-Technische Reichsanstalt adopted a temperature scale in which the thermocouple was calibrated at the freezing points of cadmium (320.9° C.), antimony (630° C.), gold (1,063° C.), and palladium (1,557° C.) and a cubic equation was used for interpolating. No comparison of this scale with the other scales described will be made here, since this would have necessitated calibration at the freezing point of palladium, which was considered inadvisable in the case of thermocouples to be used for precise measurements at lower temperatures.

The temperature scale adopted by the Bureau of Standards in 1916 was defined by the thermocouple calibrated at the freezing points of zinc and aluminum (the values for which were determined by the resistance thermometer) and at the copper point (1,083.0° C.) and the quadratic equation was retained for interpolating. This scale was used by the Bureau of Standards from 1916 to 1926 and will be designated as the Zn, Al, and Cu temperature scale.

The temperature scale which was adopted by the Physikalisch-Technische Reichsanstalt in 1924 and by the Bureau of Standards in 1926 was defined by the thermocouple calibrated at the freezing points of zinc and antimony (the values for which were determined by the resistance thermometer) and at the silver point (960.5° C.) and the gold point (1,063.0° C.) with the cubic equation for interpolating. This scale will be designated as the Zn, Sb, Ag, and Au temperature scale.

In 1927 the Seventh General Conference of Weights and Measures, representing 31 nations, unanimously adopted the International Temperature Scale referred to above. This scale in so far as the temperature range 660° to 1,063° C. is concerned is merely the Zn, Sb, Ag, and Au scale with the zinc point omitted. In putting this scale into use it has been necessary for the Bureau of Standards to abandon all of the three fixed points used previous to 1926 and to substitute three other points. It is the purpose of this work to determine how much change this has caused in the temperature scale, and to make available comparisons between some of the various scales used at different times by the Bureau of Standards.

A list of freezing points available for the calibration of thermocouples and used in defining various temperature scales in the range 400° to 1,100° C. is given in Table 1.

TABLE 1.—*Freezing points available for calibration of thermocouples*

	°C.
1. Temperature of freezing zinc	419. 47
2. Temperature of freezing antimony	630. 52
3. Temperature of freezing aluminum	659. 23
4. Temperature of freezing silver	960. 5
5. Temperature of freezing gold	1, 063. 0
6. Temperature of freezing copper in a reducing atmosphere	1, 083

The temperatures given are those corresponding to a pressure of one standard atmosphere. The values for the freezing points of zinc, antimony, and aluminum are for the particular samples employed by the Bureau of Standards and have been determined with the platinum resistance thermometer, which defines the International Temperature Scale up to 660° C. The values given for the freezing points of silver and gold, basic fixed points, and for the freezing point of copper, a secondary point, are those assigned to the various points by international agreement in the International Temperature Scale.

It would be desirable to have a suitable fixed point between the freezing point of aluminum (659.23° C.) and the freezing point of silver (960.5° C.) which could be used as a secondary point for determining the reproducibility of the various temperature scales. Such a point would also be useful in the calibration of optical pyrometers in this temperature range. The freezing point of the eutectic alloy of silver and copper, 71.9 per cent Ag, 28.1 per cent Cu, by weight, has been used to some extent at the Bureau of Standards for the above purposes. This material behaves very much as an element in so far as freezing and melting are concerned. We have no record of gas thermometer measurements on the freezing point of this alloy, but the value 779° C. was assigned to this point by the bureau as a result of thermocouple measurements. It is also the purpose of this work to determine the freezing point of the copper-silver eutectic alloy on the International Temperature Scale to an accuracy of 0.1° C.

III. APPARATUS AND PROCEDURE

The thermocouples used in this investigation were taken from the thermocouple stock prepared by the Bureau of Standards. Both the platinum and platinum-rhodium were spectroscopically pure. The composition of the alloy wire was as nearly 10 per cent rhodium as can be determined by present methods of analysis. Both of the couples were electrically annealed for six hours at 1,500° C. before being used. These two thermocouples will be designated E_2 and E_3.

Table 2 gives the data available on the purity and origin of the freezing point samples employed.

TABLE 2.—*Freezing point samples*

Sample	Purity	Prepared by—
	Per cent	
Zinc	99.993	New Jersey Zinc Co.
Antimony	99.9+	C. A. F. Kahlbaum, Berlin.
Aluminum	99.81	Aluminum Co. of America.
Silver	[1] 99.9+	U. S. Bureau of the Mint.
Gold	[2] 99.99	Do.
Copper	99.987	Raritan Copper Co.
Ag-Cu eutectic	(3)	Bureau of Standards.

[1] Proof silver. [2] Proof gold. [3] Silver, 71.9 per cent; copper, 28.1 per cent.

All of the above materials were used in Acheson graphite crucibles 15 cm deep and 3 cm inside diameter with a wall 9 mm thick. All of the materials, with the exception of gold, were covered with flake graphite to prevent oxidation during use.

A separate electric furnace was used for each metal or alloy. All the furnaces are of identical design. Figure 1 shows the construction of the furnaces and the method of supporting and protecting the freezing point sample. The graphite crucible *H* containing the metal *M* and the pyrometer protecting tube *A* is supported by silocel cylinders *L*. The heater tube *B* is of alundum (R. A. 98); length, 38 cm; inside diameter, 5.1 cm; and wall thickness, 1.0 cm. The heater tube is wound on the outside with B. & S. gage No. 6 "chromel A" wire *C*, which is embedded in alundum cement. Two Acheson graphite diaphrams *D* are placed above the crucible in order to minimize the oxidation and to promote temperature uniformity within the metal. The furnace shell *I* is made of sheet steel rolled and riveted into a cylinder. The space *O* between the heating element and furnace shell is filled with silocel powder. The annular space between the alundum tube and furnace shell is closed at the top with clay-graphite plate *P*. The hot junction of a chromel-alumel thermocouple *E* is embedded in the heating element and the wires brought through the shell to binding posts. This thermocouple provides a convenient means of indicating or controlling the temperature of the furnaces. All the lead wires are insulated from the furnace shell with bakelite bushings *J*.

The wires of the thermocouple to be calibrated were threaded through the two 1 mm holes in a porcelain insulating tube, 50 cm long and 4 mm in diameter. This insulating tube was placed inside a glazed porcelain tube 50 cm long and 5 mm inside diameter with a wall 1 mm thick. Each protection tube and insulating tube before use was heated in a furnace to a temperature above that at which measurements were to be made in order to burn out foreign materials which might have contaminated the thermocouples. A different protection tube was used for each freezing point sample.

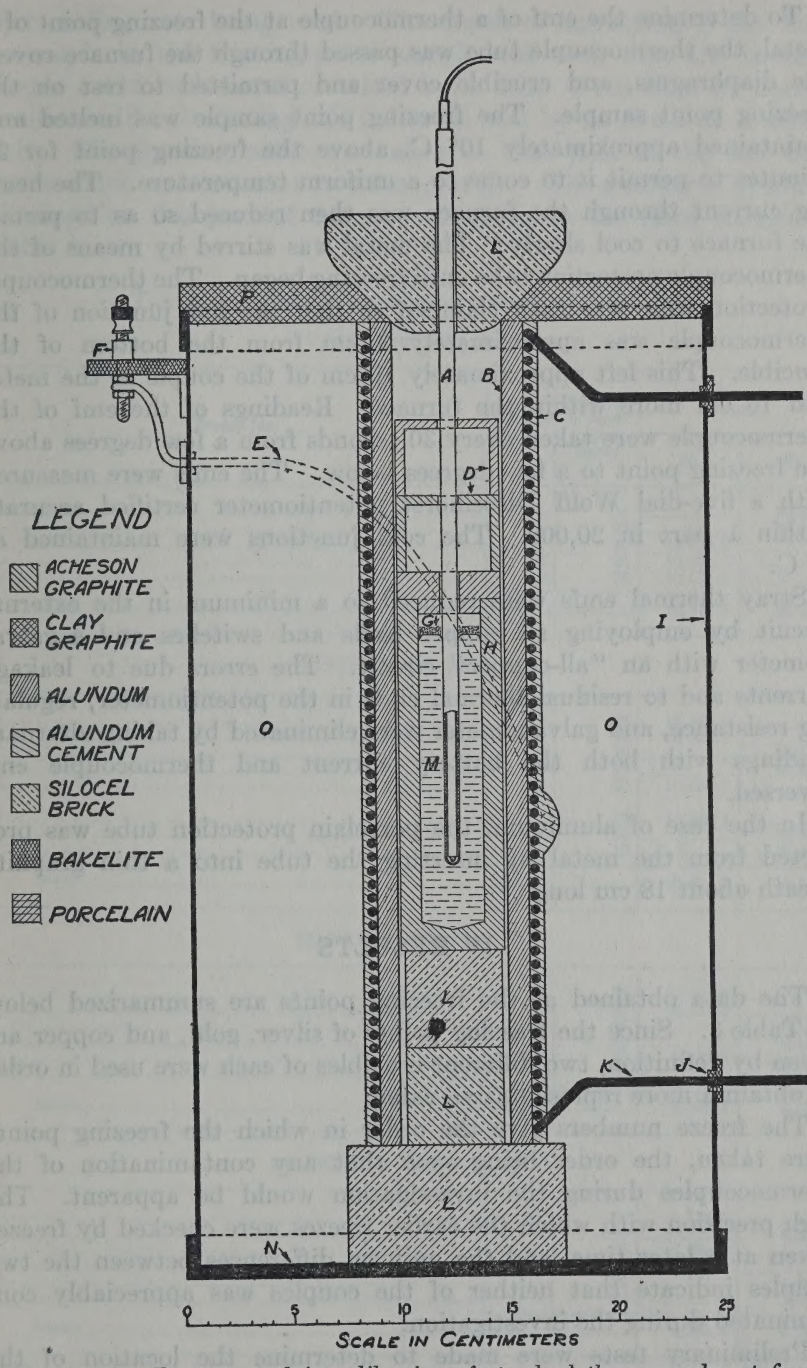

FIGURE 1.—*Furnace used in calibration of standard thermocouples at fixed points*

To determine the emf of a thermocouple at the freezing point of a metal, the thermocouple tube was passed through the furnace cover, the diaphragms, and crucible cover and permitted to rest on the freezing point sample. The freezing point sample was melted and maintained approximately 10° C. above the freezing point for 20 minutes to permit it to come to a uniform temperature. The heating current through the furnace was then reduced so as to permit the furnace to cool slowly. The metal was stirred by means of the thermocouple protection tube until freezing began. The thermocouple protection tube was then clamped so that the hot junction of the thermocouple was approximately 3 cm from the bottom of the crucible. This left approximately 10 cm of the couple in the metal and 16 cm more within the furnace. Readings of the emf of the thermocouple were taken every 30 seconds from a few degrees above the freezing point to a few degrees below. The emfs were measured with a five-dial Wolff Dieselhorst potentiometer certified accurate within 1 part in 20,000. The cold junctions were maintained at 0° C.

Stray thermal emfs were reduced to a minimum in the external circuit by employing all copper leads and switches and a galvanometer with an "all-copper" circuit. The errors due to leakage currents and to residual thermal emfs in the potentiometer, regulating resistance, and galvanometer were eliminated by taking alternate readings with both the battery current and thermocouple emf reversed.

In the case of aluminum, the porcelain protection tube was protected from the metal by inserting the tube into a thin graphite sheath about 18 cm long.

IV RESULTS

The data obtained at the freezing points are summarized below in Table 3. Since the freezing points of silver, gold, and copper are given by definition, two different crucibles of each were used in order to obtain a more representative value.

The freeze numbers give the order in which the freezing points were taken, the order being such that any contamination of the thermocouples during the investigation would be apparent. The high precision with which the earlier freezes were checked by freezes taken at a later time, and the uniform differences between the two couples indicate that neither of the couples was appreciably contaminated during the investigation.

Preliminary tests were made to determine the location of the crucible in the furnace which gave the minimum of temperature gradients within the freezing-point sample at the time freezing began. This location will give the best freezing curve for the partic-

ular cooling rate being used. The depth of immersion of the thermocouple in the freezing-point sample was such that the thermocouple could be lowered or raised by at least 1 cm from its normal position without altering the indicated emf by as much as 1 microvolt. The freezing point was taken as that part of the emf time curve which was constant to 0.3 microvolt. The number of readings obtained on this part of the curve is given in the third column of Table 3.

TABLE 3.—*Thermoelectric measurements at fixed points*

Freeze No.	Sample No.	Number of readings in freeze	International microvolts	
			E_2	E_1
COPPER POINT 1,083° C.				
1	1	34		10, 553. 2
2	1	32		10, 552. 4
3	1	40	10, 571. 6	
4	2	24	10, 571. 7	
5	2	24	10, 571. 8	
Mean			10, 571. 7	10, 552. 8
GOLD POINT 1,063.0° C.				
20	2	10	10, 334. 1	
21	2	10	10, 334. 1	
22	2	10		10, 315. 9
23	2	14		10, 316. 0
34	1	20	10, 334. 5	
35	1	18	10, 334. 1	
36	1	14		10, 315. 8
37	1	12		10, 316. 2
Mean			10, 334. 2	10, 316. 0
SILVER POINT 960.5° C.				
6	1	10	9, 137. 4	
7	1	16	9, 137. 5	
8	1	16		9, 122. 2
9	1	10		9, 122. 4
14	2	16	9, 137. 3	
19	2	20		9, 122. 6
Mean			9, 137. 4	9, 122. 4
ALUMINUM POINT 659.23° C.				
25	1	14	5, 838. 9	
26	1	14		5, 831. 7
30	1	18	5, 839. 0	
31	1	20	5, 838. 9	
32	1	22		5, 831. 9
33	1	14		5, 831. 3
Mean			5, 838. 9	5, 831. 6

TABLE 3.—*Thermoelectric measurements at fixed points.*—Con.

ANTIMONY POINT 630.52° C.

Freeze No.	Sample No.	Number of readings in freeze	International microvolts E_2	International microvolts E_3
10	1	32	5, 541. 7	
11	1	16	5, 541. 5	
12	1	30		5, 535. 0
13	1	30		5, 535. 0
Mean			5, 541. 6	5, 535. 0

ZINC POINT 419.47° C.

Freeze No.	Sample No.	Number of readings in freeze	International microvolts E_2	International microvolts E_3
15	1	30	3, 438. 2	
16	1	22	3, 438. 1	
17	1	24		3, 435. 5
18	1	26		3, 435. 6
Mean			3, 438. 2	3, 435. 6

COPPER-SILVER EUTECTIC POINT

Freeze No.	Sample No.	Number of readings in freeze	International microvolts E_2	International microvolts E_3
24	1	14	7, 115. 3	
27	1	24		7, 105. 4
28	1	24		7, 105. 4
29	1	20	7, 115. 3	
Mean			7, 115. 3	7, 105. 4

An examination of the above observations on two different crucibles of both gold and copper indicates that these points are reproducible to 0.1° C. or better. Moreover, the unpublished results of intercomparisons of thermocouples with other national laboratories indicate that the gold point is reproducible to better than 0.5° C., and probably to 0.1° C. In view of this, it seems permissible to assign values of 1,063.0° and 1,083.0° C. to the gold and copper points, respectively, since it will be shown later that the difference between these two points is 20.0° C. This is not to be understood, however, as meaning that these values are known on the Thermodynamic Centigrade Scale to this degree of accuracy.

The equations for interpolating between fixed points for both of the couples were computed for each of the four temperature scales which have been used by the Bureau of Standards since 1912. The constants of the equations are given in Tables 4 and 5. The equations are of the form $E=a+bt+ct^2$ or $E=a+bt+ct^2+dt^3$, depending upon the number of fixed points used in defining the scale. E is the emf in microvolts and t the temperature in ° C. when the cold junctions are at 0° C.

TABLE 4.—*Constants of equations for thermocouple* E_2

Temperature scale	Fixed points	Constants			
		a	*b*	*c*	*d*
Zn, Sb, and Cu	Zn, Sb, and Cu	−283.85	8.14597	0.00173372	
Zn, Al, and Cu	Zn, Al, and Cu	−280.41	8.13461	.00174128	
Zn, Sb, Ag, and Au	Zn, Sb, Ag, and Au	−319.49	8.32088	.00146639	0.00000012623
International Temperature Scale	Sb, Ag, and Au	−238.23	8.03094	.00180141	

TABLE 5.—*Constants of equation for thermocouple* E_3

Temperature scale	Fixed points	Constants			
		a	*b*	*c*	*d*
Zn, Sb, and Cu	Zn, Sb, and Cu	−281.77	8.14003	0.00172132	
Zn, Al, and Cu	Zn, Al, and Cu	−278.03	8.12764	.00172957	
Zn, Sb, Ag, and Au	Zn, Sb, Ag, and Au	−316.81	8.31197	.00145845	0.00000012420
International Temperature Scale	Sb, Ag, and Au	−236.86	8.02670	.00178808	

The calculated emfs at the fixed points and at 50° intervals from 450° to 1,100° C. are given in Tables 6 and 7.

TABLE 6.—*Temperature — emf relations for thermocouple* E_2

Temperature (° C.)	Emf in microvolts for temperature scales			
	Zn, Sb, and Cu	Zn, Al, and Cu	Zn, Sb, Ag, and Au	International Temperature Scale
419.47	[1] 3,438.2	[1] 3,438.2	[1] 3,438.2	*3,447.5*
450.00	3,732.9	3,732.8	3,733.4	*3,740.5*
500.00	4,222.6	4,222.2	4,223.3	*4,227.6*
550.00	4,720.9	4,720.4	4,721.6	*4,723.7*
600.00	5,227.9	5,227.2	5,228.2	*5,228.8*
630.52	[1] 5,541.6	5,540.9	[1] 5,541.6	[1] 5,541.6
650.00	5,743.5	5,742.8	5,743.3	5,743.0
659.23	5,839.7	[1] 5,838.9	5,839.3	5,838.9
700.00	6,267.8	6,267.0	6,267.0	6,266.1
750.00	6,800.8	6,800.0	6,799.3	6,798.3
800.00	7,342.5	7,341.7	7,340.3	7,339.4
850.00	7,892.8	7,892.1	7,890.2	7,889.6
900.00	8,451.8	8,451.2	8,449.1	8,448.8
950.00	9,019.5	9,019.0	9,017.0	9,016.9
960.50	9,139.8	9,139.3	[1] 9,137.4	[1] 9,137.4
1,000.00	9,595.8	9,595.5	9,594.0	9,594.1
1,050.00	10,180.8	10,180.7	10,180.3	10,180.3
1,063.00	10,334.4	10,334.3	[1] 10,334.2	[1] 10,334.2
1,083.00	[1] 10,571.7	[1] 10,571.7	*10,572.3*	*10,572.1*
1,100.00	*10,774.5*	*10,774.6*	*10,775.8*	*10,775.5*

[1] Calibration points.
Figures in italics represent extrapolated values.

TABLE 7.—*Temperature—emf relations for thermocouple E_3*

Temperature (° C.)	Emf in microvolts for temperature scales			
	Zn, Sb, and Cu	Zn, Al, and Cu	Zn, Sb, Ag, and Au	International Temperature Scale
419.47	[1] 3,435.6	[1] 3,435.6	[1] 3,435.6	*3,444.7*
450.00	3,729.8	3,729.6	3,730.2	*3,737.2*
500.00	4,218.6	4,218.2	4,219.3	*4,223.5*
550.00	4,716.0	4,715.4	4,716.6	*4,718.7*
600.00	5,221.9	5,221.2	5,222.4	*5,222.9*
630.52	[1] 5,535.0	5,534.2	[1] 5,535.0	[1] 5,535.0
650.00	5,736.5	5,735.7	5,736.3	5,736.0
659.23	5,832.4	[1] 5,831.6	5,832.1	5,831.6
700.00	6,259.7	6,258.8	6,258.8	6,258.0
750.00	6,791.5	6,790.6	6,790.0	6,789.0
800.00	7,331.9	7,331.0	7,329.8	7,328.9
850.00	7,880.9	7,880.1	7,878.4	7,877.7
900.00	8,438.5	8,437.8	8,435.8	8,435.5
950.00	9,004.8	9,004.2	9,002.3	9,002.2
960.50	9,124.8	9,124.2	[1] 9,122.4	[1] 9,122.4
1,000.00	9,579.6	9,579.2	9,577.8	9,577.9
1,050.00	10,163.0	10,162.8	10,162.5	10,162.5
1,063.00	10,316.1	10,316.0	[1] 10,316.0	[1] 10,316.0
1,083.00	[1] 10,552.8	[1] 10,552.8	*10,553.4*	*10,553.3*
1,100.00	*10,755.1*	*10,755.2*	*10,756.4*	*10,756.1*

[1] Calibration points.
Figures in italics represent extrapolated values.

The differences between any two temperature scales as determined by thermocouple E_2 agree with the same differences obtained with E_3 to within 0.2 microvolts (0.02° C.). The average differences in degrees between any of the above scales and the International Temperature Scale (I. T. S.) are given in Table 8 for the temperature range 660° to 1,100° C.

TABLE 8.—*Differences between temperature scales*

Temperature (° C.)	I. T. S.—Zn, Sb, and Cu	I. T. S.—Zn, Al, and Cu	I. T. S.—Zn, Sb, Ag, and Au	Temperature (° C.)	I. T. S.—Zn, Sb, and Cu	I. T. S.—Zn, Al, and Cu	I. T. S.—Zn, Sb, Ag, and Au
	°C.	*°C.*	*°C.*		*°C.*	*°C.*	*°C.*
660	−0.08	0.00	−0.04	960.5	−0.21	−0.16	0.00
700	−.16	−.08	−.08	1,000	−.15	−.12	+.01
750	−.24	−.16	−.09				
800	−.28	−.20	−.08	1,050	−.04	−.03	.00
850	−.29	−.22	−.06	1,063	−.01	.00	.00
				1,083	+.04	+.03	−.01
900	−.26	−.21	−.03	1,100	+.08	+.08	−.03
950	−.23	−.18	−.01				

Table 8 shows (1) that the maximum difference between the International Temperature Scale and the Zn, Sb, and Cu temperature scale used by the Bureau of Standards from 1912 to 1916 is approximately 0.3° C. at 850° C.; (2) that the maximum difference between the International Temperature Scale and the Zn, Al, and Cu scale used by the Bureau of Standards from 1916 to 1926 is approximately

0.2° C. at 850° C.; and (3) that the maximum difference between the International Temperature Scale and the Zn, Sb, Ag, and Au temperature scale used by the Bureu of Standards from 1926 to 1927 is approximately 0.1° C. at 750° C.

Data previously obtained by the bureau with other couples confirms the data in column 4 of Table 8, namely, that the maximum difference between the International Temperature Scale and the Zn, Sb, Ag, and Au temperature scale is not greater than 0.1° C. These differences in column 4, Table 8, agree in magnitude but not in sign with the differences obtained by Henning and Otto.

The data of Table 8 depend upon assigning the temperatures given in Table 1,to the zinc, antimony, aluminum, silver, gold, and copper points. This naturally raises the question as to whether these same temperatures have always been assigned to the points since 1912 and whether the metals used earlier were identical with those used in this investigation. As concerns the first three points, these were determined with the resistance thermometer, calibrated at the sulphur boiling point (444.6° C. at normal atmospheric pressure), and thus a value consistent with the International Temperature Scale was always assigned to each lot of metal used. Silver, gold, and copper of very high purity have been available, and it may be taken for granted that pure metal was used in all instances. Since 1912 the temperatures assigned to these three points have been consistently those listed in Table 1.

In order to examine the reproducibility of the various temperature scales, the thermocouples were compared over the temperature range from the zinc point to 1,100° C. The hot junctions of the thermocouples were welded together in order to insure equality of temperature between these junctions of the couples. The thermocouples were then placed in a platinum wound resistance furnace and observations of the emfs of the couples taken at various temperatures. In order to eliminate errors due to slow changes in the temperature of the furnace during an observation, readings were also made of the emf between the two platinum wires and the emf between the two alloy wires. Each of these quantities is small and does not change by more than 0.1 microvolt for a temperature change of 5° C. The sum of these two emfs, therefore, gives accurately the difference between the two couples for any temperature within 5° C., of the point of observation.

The results of these observations are plotted in Figure 2. The difference between the two thermocouples as determined from the equations for any of the four temperature scales given above does not differ from the observed differences in Figure 2 by more than 0.2 microvolts (0.02° C). Thus, it is seen that with good thermocouples any of the above temperature scales are definite and reproducible to

an accuracy approaching the limit of accuracy of emf measurements. Examples of this order of reproducibility are given below.

The copper-silver eutectic point on the International Temperature Scale as determined by thermocouple E_2 is 779.39° C. The same point as determined by thermocouple E_3 is 779.41° C. The mean value of 779.4° C. is probably accurate to 0.1° C.

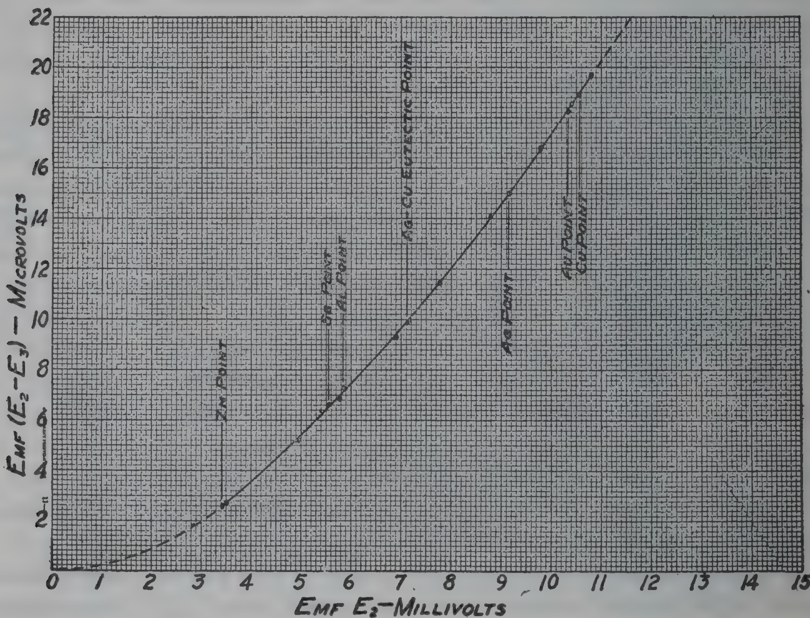

FIGURE 2.—*Observed differences in emf between thermocouples E_2 and E_3*

The difference between the freezing points of gold and copper as determined by each of the above temperature scales is given in Table 9.

TABLE 9.—*Difference between freezing points of gold and copper*

Temperature scale	Difference in °C. by thermocouple	
	E_2	E_3
International Temperature Scale	19.97	19.96
Zn, Sb, Ag, and Au scale	19.95	19.95
Zn, Al, and Cu scale	20.01	20.00
Zn, Sb, and Cu scale	20.02	20.01
Mean	19.98	

The values on the first two scales in the table are obtained by extrapolating above the gold point to obtain the copper point whereas the values by the last two scales in the table are obtained by

interpolating to obtain the gold point. Therefore, if a value of 1,063.0° C. is assigned to the freezing point of gold, a value of 1,083.0° C. should be assigned to the freezing point of copper.

V. SUMMARY AND CONCLUSIONS

The differences between four widely used thermoelectric temperature scales based upon (1) Sb, Ag, and Au; (2) Zn, Sb, Ag, and Au; (3) Zn, Al, and Cu; and (4) Zn, Sb, and Cu, as calibration points with the temperatures given in Table 1, have been determined. The maximum difference between (1) and (2) was found to be 0.1° C., between (1) and (3) 0.2° C., and between (1) and (4) 0.3° C.

A comparison of the differences between the calibration curves for two thermocouples with the differences between the two couples found by direct measurement indicates that any of the above temperature scales are reproducible to better than 0.1° C.

The freezing point of the copper-silver eutectic alloy 71.9 per cent silver and 28.1 per cent copper, on the International Temperature Scale was found to be 779.4° C. ± 0.1° C.

The difference between the freezing points of gold and copper was found to be 20.0° C. ± 0.1° C.

Methods used at the Bureau of Standards in realizing the International Temperature Scale in the range 660° to 1,063° C. are described in detail.

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WASHINGTON, April 23, 1929.

U. S. GOVERNMENT PRINTING OFFICE: 1929